Quantum Electronics **31** (9) 845 – 846 (2001)

DISCUSSION

PACS numbers: 52.25.-b
DOI: 10.1070/QE2001v031n09ABEH002059

On a ‘metastable’ plasma

S N Andreev, A A Rukhadze, A A Samokhin

***Abstract*. Attention is drawn to the insufficient validity of a number of conclusions concerning the fundamentals of statistical physics made in a paper of A M Tkachev and S I Yakovlenko [Quantum Electron. v.30 p.1077 (2000)].**

Keywords: *metastable states, recombination, entropy, plasma.*

The authors of recent paper [1] claim that paper [2] can be considered as the first experimental demonstration of a metastable state of a supercooled plasma, which they theoretically predicted earlier. In our opinion, such a statement is not adequately justified for reasons that have been already partially discussed in Ref. [3]. It was noted in Ref. [3] that the theoretical interpretation of the numerical experiments mentioned in Ref. [1] does not require at all the rejection of the principle of detailed balancing and a radical revision of other fundamentals of physical kinetics and statistical mechanics.

Recall in this connection that the fact of the existence of different metastable states is well known [4] and does not suggest that the fundamentals of statistical physics or quantum mechanics should be revised. The phase transitions and metastable states in a nonideal plasma have been studied by various authors in many papers (see, for example, papers [5 – 8] and references therein). In particular in Ref. [8], the nature of the anomalous long lifetime of a condensed excited state at high excitation levels related to the collective suppression of recombination was discussed.

The authors of Ref. [1] do not cite in their papers the studies [5 – 8], and in fact treat 'metastability' as a decrease in the recombination rate compared to the rate determined by the known expression for three-body recombination [9]. They not only never mentioned about the simulation of recombination in a plasma with parameters corresponding to the experimental conditions [2] but emphasised instead that to observe the recombination delay, it is reasonable to consider a system of heavy charged particles because the observation of such effects in an electron–ion plasma is problematic.

However, in the case of charge particles with close masses, the effect of elastic reflection from walls preventing the plasma expansion becomes substantial under the conditions of the model [1], when the mean free path of the particles in volume processes proves to be comparable with the distance between the walls or greater.

This circumstance was considered in Ref. [3], where it was shown that the interaction of a pair of Coulomb particles with walls results in their distribution over the total energy in the centre-of-mass system, which corresponds to a microcanonical ensemble and substantially differ from the Boltzmann distribution. In addition, the distribution of the particles over their kinetic energy in the laboratory coordinate system resembles the Maxwell distribution. Relaxation to the equilibrium in such an ensemble occurs during approximately ten collisions with the walls, the relaxation being predominantly determined by recombination or ionisation, depending on the type of the initial nonequilibrium distribution.

It follows from these results that the interpretation of the behaviour of an ensemble of particles within a limited volume should take into account the role of reflections from the walls, which can affect both relaxation of the medium and the shape of the equilibrium distribution. Otherwise, the explanation of the results of numerical simulations within the framework of the accepted fundamentals of statistical mechanics can indeed involve difficulties. In our opinion, the authors of Ref. [1] encountered such difficulties in their previous papers, where they have considered ‘the metastable state’ only in volume processes, without specifying the corresponding metastable phase, which is in the equilibrium with the mirror-reflecting walls of the limited volume, and without determining the critical nuclei of this phase (heterophase fluctuations) which are dynamically unstable in the metastable phase volume.

The statement of the authors of Ref. [1] that ‘the exponential decay of the distribution of electrons over a total energy in the region of large negative energies results in a substantial delay of recombination’ sounds strange, because the electron distribution function at the initial moment is assumed zero in this region. The references to the invariance of the Gibbs entropy (the mean logarithm of the total distribution function), which supposedly prevents the recombination, or to Ref. [10] where the point of view presented in Ref. [1] was supported, are also inconclusive, because the question remains open why such arguments are not valid for all other known phase transitions or metastabilities.

In experimental paper [2], nothing is told about ‘metastability’, but the authors point out that the observed long

---

S N Andreev, A A Rukhadze, A A Samokhin General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia

Received 30 January 2001
Kvantovaya Elektronika **31** (9) 845 – 846 (2001)
Translated by M N Sapozhnikov

lifetimes of an ultracold plasma obtained by them are 'the first distinct evidence' that the theory of three-body recombination and its generalisation [11] cannot be applied to the experiment conditions [2]. Note in this connection a substantial circumstance, which was ignored in Refs [1, 2], that the expression for three-body recombination [9] is initially invalid for plasma parameters reported in Refs [1, 2] because it predicts the recombination times as short as, for example, 0.5 fs and 2 ns, during which electrons can pass only over a small part of the distance between ions.

This also means that the use of the expression for three-body recombination at low temperatures beyond the limits of its formal applicability gives the overestimated recombination rates compared to the rates that should be obtained from experiments or a correct theory. In this case, it seems that there is no point in assigning any physical meaning to such 'a recombination delay' because this 'effect' is caused by the violation of approximations and assumptions adopted in deriving the corresponding expressions. Unfortunately, the authors of Ref. [1] not only do not point out the theoretical limits of the applicability of the formula for three-body recombination from Ref. [9] but pay no attention to their existence at all, by using this formula well beyond the limits of its physical meaning, making no difference from the case considered by them earlier.

The above comments dot not exclude, of course, the possibility of the efficient use of numerical solutions of the Newton equations for a system of Coulomb particles, both for analysis of methodical questions and comparison with the corresponding experimental data. In particular, the agreement of the results of numerical simulation [1] with the lifetime of a plasma bunch measured in Ref. [2] does not contradict to the possibility of a classical description of some properties of plasmas. At the same time, the influence of radiation in the model of classical particles, which was neglected in Ref. [1], can substantially change the trajectories of the particles [12] and all the conclusions related to this circumstance.

Various approaches based on the classical model of a Coulomb plasma have their regions of applicability and their limitations, which should by correctly taken into account in the interpretation of the results of numerical simulations in order not to revise needlessly the fundamentals of statistical physics.

Acknowledgements. The authors thank A M Ignatov and staff members of the theoretical department of General Physics Institute, RAS for useful discussions.

References

1. Tkachev A N, Yakovlenko S I *Kvantovaya Elektron.* **30** 1077 (2000) [*Quantum Electron.* **30** 1077 (2000)]
2. Killian T C, Kulin S, Bergeson S D, Orozco S D, Orzel C, Rolston S L *Phys. Rev. Lett.* **83** 4776 (1999)
3. Ignatov A M, Korotchenko A I, Makarov V P, Rukhadze A A, Samokhin A A *Usp. Fiz. Nauk* **165** 113 (1995)
4. Prokhorov A M (Ed.) *Fizicheskii enziklopedicheskii slovar'* (Physical Encyclopedic Dictionary) (Moscow: Sovetskaya Entsiklopedia, 1983)
5. Biberman L M, Norman G E *Tepofiz. Vys. Temp.* **7** 822 (1969)
6. Norman G E *Khim. Fiz.* **18** 78 (1999); Norman G E *Contrib. Plasma Phys.* **41** 127 (2001)
7. Manykin E A, Ozhovan M I, Poluektov P P *Zh. Eksp. Teor. Fiz.* **84** 442 (1983)
8. Manykin E A, Ozhovan M I, Poluektov P P *Chim. Phys.* **18** 87 (1999)
9. Lifshits E M, Pitaevskii L P *Fizicheskaya kinetika* (Physical Kinetics) (Moscow: Nauka, 1979)
10. Kadomtsev B B *Dinamika i informatsiya* (Dynamics and Information) (Moscow: Izd. Usp. Fiz. Nauk, 1997)
11. Hahn Y *Phys. Lett. A* **231** 82 (1997)
12. Gertsenshtein M E, Kravtsov Yu A *Zh. Eksp. Teor. Fiz.* **118** 761 (2000)